FORMING ALCOA ALUMINUM

ALUMINUM COMPANY OF AMERICA

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INTRODUCTION

FORMING is one of the most important methods of metal fabrication. The principles of forming all metals are basically the same, but for each metal there is a difference in the amount of deformation, the details of tool design, annealing procedures, etc. This booklet describes the numerous methods of forming aluminum and its alloys. The data and procedures are those which by experience have been found most satisfactory in commercial practice.

ALUMINUM ALLOYS

ALUMINUM is one of the most workable of the common metals. The metalworker, however, should not think of aluminum as just one material, but rather as a series of alloys which come in a wide range of mechanical properties. The characteristics of these alloys affect shop practices and should be thoroughly understood.

These alloys may be classified into two groups; namely, nonheat-treatable and heat-treatable. The harder tempers are produced in the nonheat-treatable alloys by cold-working, and the properties of the heat-treatable alloys are increased by thermal treatments.

NONHEAT-TREATABLE ALLOYS

The nonheat-treatable alloys include Alcoa 2S, 3S, 4S, B50S, 52S and 56S. These alloys are supplied in a wide range of properties which are the result of both composition and degree of strain hardening. The properties of the various products of these alloys are designated by symbols which indicate the degree of strain hardening or the method of production.

The symbol -F is used to designate as-fabricated materials with no attempt to control the degree of strain hardening; while the symbol -O designates annealed material. When the desired tensile strength is obtained by cold-working only, the resulting temper is designated by the symbol -H1 followed by a number indicating the relative amount of cold-work. Thus, the hardest commercial temper generally obtained in this manner is designated by the complete symbol -H18. Materials having tensile strengths midway between those of the fully annealed temper, -O, and the hardest temper, -H18, are designated by the symbol -H14. Similarly, the symbol -H12 indicates strengths midway between the -O and the -H14 tempers; while -H16 indicates strengths midway between the -H14 and -H18 levels.

If, however, the tempers are obtained by cold-working followed by partial annealing, the basic symbol becomes -H2. The different levels of strengths are designated in the same manner as for the materials which received only the cold-working operation. The

designations thus become -H22, -H24, -H26 and -H28. Generally, the materials in the -H2 tempers will have the same tensile strength but a lower yield strength and higher elongation than in the corresponding -H1 tempers. The alloys 2S and 3S are currently produced in either the temper-rolled, -H1, or partially annealed, -H2, tempers. It is recommended that initial trials of these alloys should be made in the temper-rolled condition unless

TABLE 1

STANDARD PRODUCTS[1]—WROUGHT ALLOYS

Alloy	Sheet	Plate	Wire	Rod	Bar	Extruded Shapes, Tube and Pipe	Drawn Tube and Pipe[3]
Nonheat-treatable Alloys							
2S	*	*	*	*	*	..	..
3S	*	*	*	*	*	*	*
Alclad 3S	*	*	..	..	..	..	*[4]
4S	*	*	..	..	..	..	*
Alclad 4S	*	*	..	..	..	..	..
B50S	*	*	..	..	..	..	..
52S	*	*	*	*	*	..	*
56S	..	..	*	*	..	..	..
Alclad 56S	..	..	*	..	..	..	..
Heat-treatable Alloys							
11S	..	..	*	*	[2]	..	..
14S	..	..	..	*	*	*	..
Alclad 14S	*	*	..	..	..	..	..
17S	..	..	*	*	*	..	..
24S	*	*	*	*	*	*	*
Alclad 24S	*	*	..	..	..	..	..
61S	*	*	*	*	*	*	*
62S	..	..	..	..	..	*	*
63S	..	..	..	..	..	*	*
75S	*	*	*	*	*	*	..
Alclad 75S	*	*	..	..	..	..	..

[1] Products marked * are produced in routine commercial production. Sales representatives of Aluminum Company of America should be consulted concerning the possibility of obtaining other products in the various alloys. See list of sales offices on page 75 of this book.
[2] Available in hexagons only.
[3] For extruded tubing, use column for extruded shapes.
[4] Coating on inside only.

TABLE 2

NOMINAL COMPOSITION OF WROUGHT ALUMINUM ALLOYS[1]

Alloy	Per Cent of Alloying Elements—Aluminum and Normal Impurities Constitute Remainder								
	Copper	Silicon	Manganese	Magnesium	Zinc	Nickel	Chromium	Lead	Bismuth
Nonheat-treatable Alloys									
2S[2]	...	...	...	...	...	...	...	...	...
3S	...	...	1.2	...	...	...	...	...	...
4S	...	...	1.2	1.0	...	...	...	...	...
B50S	...	...	...	1.2	...	...	...	...	...
52S	...	...	...	2.5	...	...	0.25	...	...
56S	...	...	0.1	5.2	...	...	0.1	...	...
Heat-treatable Alloys									
11S	5.5	...	...	...	...	...	...	0.5	0.5
14S	4.4	0.8	0.8	0.4	...	...	...	...	...
17S	4.0	...	0.5	0.5	...	...	...	...	...
24S	4.5	...	0.6	1.5	...	...	...	...	...
61S	0.25	0.6	...	1.0	...	...	0.25	...	...
62S	0.25	0.6	...	1.0	...	...	...	...	...
63S	...	0.4	...	0.7	...	...	...	...	...
75S	1.6	...	...	2.5	5.6	...	0.3	...	...

[1] Heat-treatment symbols have been omitted since composition does not vary for different heat-treatment practices.
[2] 99 per cent minimum aluminum.

it is specifically known that the partially annealed material will be preferable or at least as satisfactory.

Certain of the nonheat-treatable alloys, notably 4S, B50S, 52S and 56S, upon storage at room temperature after strain hardening show measurable decreases in strengths and increases in elongations until a reasonably stable condition is attained after six months to one year. These same decreases in strengths can be secured after a short treatment at elevated temperatures, thus making it possible to supply the intermediate and hard-rolled tempers of these alloys in a stabilized condition which is

TABLE 3

TYPICAL① MECHANICAL PROPERTIES OF WROUGHT ALLOYS

Alloy and Temper	Tensile Strength, Psi	Yield Strength (Offset = 0.2%) Psi	Elongation Per Cent in 2 In.		Brinell Hardness, 500-kg. Load 10-mm. Ball	Shearing Strength, Psi
			Sheet Specimen (1/16 In. Thick)	Round Specimen (1/2 In. Diameter)		
Nonheat-treatable Alloys						
2S-O	13,000	5,000	35	45	23	9,500
2S-H12	15,500	14,000	12	25	28	10,000
2S-H14	17,500	16,000	9	20	32	11,000
2S-H16	20,000	18,000	6	17	38	12,000
2S-H18	24,000	22,000	5	15	44	13,000
3S-O	16,000	6,000	30	40	28	11,000
3S-H12	19,000	17,000	10	20	35	12,000
3S-H14	21,500	19,000	8	16	40	14,000
3S-H16	25,000	22,000	5	14	47	15,000
3S-H18	29,000	26,000	4	10	55	16,000
Alclad 3S	Properties substantially same as for 3S.					
4S-O	26,000	10,000	20	25	45	16,000
4S-H32	31,000	22,000	10	17	52	17,000
4S-H34	34,000	27,000	9	12	63	18,000
4S-H36	37,000	31,000	5	9	70	20,000
4S-H38	40,000	34,000	5	6	77	21,000
Alclad 4S	Properties substantially same as for 4S.					
B50S-O	21,000	8,000	24	..	36	14,000
B50S-H32	24,500	21,000	9	..	45	16,000
B50S-H34	27,500	24,000	8	..	50	17,000
B50S-H36	29,500	26,000	7	..	54	18,000
B50S-H38	31,000	28,000	6	..	57	19,000
52S-O	27,000	12,000	25	30	45	18,000
52S-H32	34,000	27,000	12	18	62	20,000
52S-H34	37,000	31,000	10	14	67	21,000
52S-H36	39,000	34,000	8	10	74	23,000
52S-H38	41,000	36,000	7	8	85	24,000
56S-O	42,000	22,000	..	35	..	26,000
56S-H18	63,000	59,000	..	10	..	34,000
56S-H38	60,000	50,000	..	15	..	32,000

See footnotes, page 12.

TABLE 3—Continued

TYPICAL① MECHANICAL PROPERTIES OF WROUGHT ALLOYS

Alloy and Temper	Tensile Strength, Psi	Yield Strength (Offset = 0.2%) Psi	Elongation Per Cent in 2 In.		Brinell Hardness, 500-kg. Load 10-mm. Ball	Shearing Strength, Psi
			Sheet Specimen (1/16 In. Thick)	Round Specimen (1/2 In. Diameter)		
Heat-treatable Alloys						
11S-T3②	55,000	48,000	..	15	95	32,000
11S-T6	57,000	39,000	..	17	97	34,000
11S-T8	59,000	45,000	..	12	100	35,000
14S-O	27,000	14,000	..	18	45	18,000
14S-T4	62,000	40,000	..	20	105	38,000
14S-T6	70,000	60,000	..	13	135	42,000
Alclad 14S-O	25,000	10,000	21	..	..	18,000
Alclad 14S-T3	63,000	40,000	20	..	..	37,000
Alclad 14S-T4	61,000	37,000	22	..	..	37,000
Alclad 14S-T6	68,000	60,000	11	..	..	41,000
17S-O	26,000	10,000	..	22	45	18,000
17S-T4	62,000	40,000	..	22	105	38,000
24S-O	27,000	11,000	19	22	47	18,000
24S-T3	70,000	50,000	18	..	120	41,000
24S-T4	68,000③	48,000	20	19	120	41,000
24S-T36	72,000	57,000	14	..	130	42,000
Alclad 24S-O	26,000	11,000	19	..	..	18,000
Alclad 24S-T3	64,000	44,000	18	..	..	40,000
Alclad 24S-T4	64,000	42,000	19	..	..	40,000
Alclad 24S-T36	67,000	53,000	11	..	..	41,000
Alclad 24S-T81	65,000	60,000	6	..	..	......
Alclad 24S-T86	70,000	66,000	6	..	..	......
61S-O	18,000	8,000	22	30	30	12,500
61S-T4	35,000	21,000	22	25	65	24,000
61S-T6	45,000	40,000	12	17	95	30,000
62S-O	17,000	6,500	..	30	28	12,000
62S-T4	35,000	21,000	..	25	65	24,000
62S-T6	45,000	40,000	..	17	95	30,000
63S-T5	27,000	21,000	12	..	60	17,000
63S-T6	35,000	31,000	12	..	73	22,000
63S-T42	22,000	13,000	20	..	42	14,000
63S-T83	38,000	36,000	10	..	82	......
63S-T831	32,000	29,000	10	..	70	......
63S-T832	45,000	40,000	10	..	95	......

See footnotes, page 12.

TABLE 3—Concluded

TYPICAL① MECHANICAL PROPERTIES OF WROUGHT ALLOYS

Alloy and Temper	Tensile Strength, Psi	Yield Strength (Offset = 0.2%) Psi	Elongation Per Cent in 2 In.		Brinell Hardness, 500-kg. Load 10-mm. Ball	Shearing Strength, Psi
			Sheet Specimen (1/16 In. Thick)	Round Specimen (1/2 In. Diameter)		
Heat-treatable Alloys—Continued						
75S-O	33,000	15,000	17	16	60	22,000
75S-T6④	82,000	72,000	11	11	150	49,000
Alclad 75S-O	32,000	14,000	17	..	..	22,000
Alclad 75S-T6	76,000	67,000	11	..	..	46,000

①The values given in this table are averages which take into account the variations introduced by the size, shape or method of manufacture.
②For sizes up to 1½ inches. For larger sizes, the strengths will be somewhat lower.
③The strengths of extrusions more than about ¾ inch thick will be 15 to 20 per cent higher.
④The values given are for sheet. Extrusions will have strengths about 8 to 10 per cent higher.

not subject to additional change upon storage at room temperature. Materials produced in this way are designated by the basic symbol, -H3, with the degree of strain hardening designated in the same manner as that used for the -H1 and -H2 conditions. For example, 52S-H34 has been strain hardened and then stabilized to produce a tensile strength intermediate between that of the hard and soft tempers. The stabilized materials are definitely more formable than comparable materials which have not been given this treatment. Products of the alloys mentioned above are furnished in the -H3 temper unless for some specific reason the -H1 or -H2 tempers are desired. The mechanical properties of the nonheat-treatable alloys in the various tempers will be found in Table 3, on page 10.

In forming operations involving nonheat-treatable alloys, generally the temper of the material is selected so that the forming operation can be completed without recourse to intermediate annealing operations. However, in some cases, certain forming

sequences require softening before the succeeding step, and the recommendations given in Table 4 are suggested for the various alloys. No specific limits can be set, as the treatments will vary depending upon the equipment available in the customer's plant and the part being annealed.

TABLE 4
RECOMMENDED CONDITIONS FOR THERMAL TREATMENT OF WROUGHT ALUMINUM ALLOYS

Annealing of Nonheat-treatable Alloys

Alloy	Metal Temperature °F	Approx. Time of Heating Hrs.	Temper Designation
2S	650	①	–0
3S, Alclad 3S	775	①	–0
4S, Alclad 4S	650	①	–0
B50S	650	①	–0
52S	650	①	–0
56S	650	①	–0

①Time in the furnace need not be longer than is necessary to bring all parts of the load to the annealing temperature. Cooling rate is unimportant.

HEAT-TREATABLE ALLOYS

The higher strengths of the heat-treatable alloys make these alloys desirable for use in structures and parts of airplanes, buses, railroad cars, ships and truck bodies. Alcoa alloys 14S, 24S, 61S, 62S and 75S are the heat-treatable alloys most generally used in these applications. The strengths of these alloys are developed by solution heat treatment at elevated temperatures followed by quenching and aging at room temperature (natural aging) or a precipitation treatment at elevated temperatures known as artificial aging.

The solution heat-treating step consists of heating the particular product at temperatures ranging from 860-980°F, depending upon the particular alloy involved, for a sufficient period to obtain maximum solid solution of the alloying constituents. The

product is then quenched rapidly in cold water to retain the maximum quantities of the hardening constituents in solid solution. Subsequent to quenching, all the alloys will harden at room temperature by a precipitation process generally termed natural aging. The alloys 14S, 17S and 24S attain substantially full properties after approximately 4 days. The progress of natural aging for the alloys 14S, 24S, 61S and 75S is illustrated by the curves in Figures 1 and 2 on pages 15 and 18 respectively.

The alloys 61S, 62S, 63S and 75S harden by the natural aging process as previously mentioned, but are not generally used in this temper. A precipitation treatment at elevated temperatures is required to produce the maximum strengths. A treatment of this nature is also applicable to products of 14S and 24S, and substantially higher strengths, particularly yield strength, are obtained by artificial aging. Recommended solution heat treatments and precipitation heat treatments of these materials are given in Table 5. The mechanical properties of the heat-treatable alloys in the several tempers available are listed in Table 3, page 11.

Limited forming of heat-treatable alloy products is possible in the fully heat-treated tempers, considerably more in the naturally aged tempers than in the artificially aged tempers, while maximum formability is attained in the annealed temper. Forming in the "as-quenched" condition immediately after quenching will be most effective and this state can be maintained by refrigeration as illustrated in Figure 3 for 24S. Similar conditions hold for the other heat-treatable alloys. Parts formed in this manner may be used in the naturally aged temper or can be artificially aged to develop the maximum strengths.

Upon storage at room temperature, natural aging progresses as shown in Figure 3 and maximum formability is realized for only a short period after quenching as the strengths increase rapidly after an interval of about one hour. Parts of these alloys formed in the annealed temper should be heat treated and aged according to the schedule given in Table 5.

The (basic) temper designations for the heat-treatable alloys are:

-O Annealed or dead soft material.

-T3 This temper designation applies to those products where cold work is applied after heat treatment in order to increase the

strength, or where the effect of cold-work, such as flattening or straightening, is recognized in applicable property specifications. Alclad 14S and 24S flat sheet heat treated by Alcoa are designated by -T3.

-T4 This temper designation applies to products which are quenched from the solution heat-treating temperature and naturally aged to a substantially stable condition. Alclad 14S and 24S sheet and plate which are not cold-worked after quenching are designated by -T4. Since the effect of flattening and straightening operations are not recognized in the specifications for 61S flat sheet, this product is designated as 61S-T4.

-T6 This temper designation applies to products given the solution heat treatment and then artificially aged. No cold-working is done, and the effect of flattening or straightening is not recognized in applicable specifications; 61S-T6, 14S-T6, 75S-T6.

Other specialized tempers are available for many products of the heat-treatable alloys. The customer should consult the booklet, *Alcoa Aluminum and Its Alloys*, or the nearest Alcoa Sales Office for information regarding these tempers.

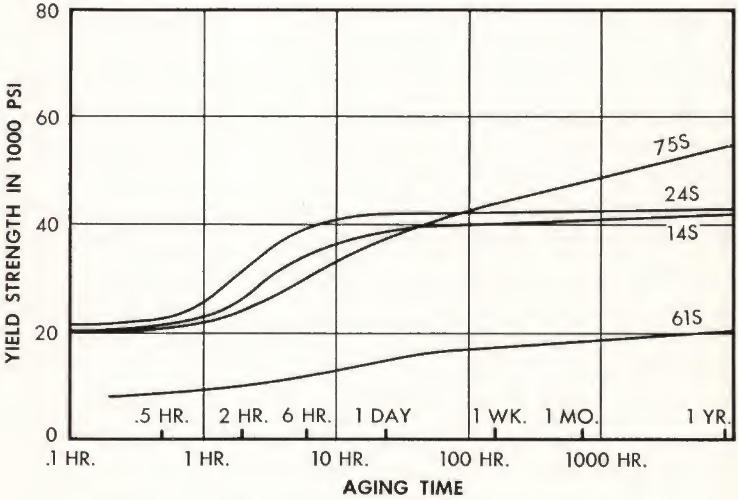

Figure 1—Aging time showing increase in yield strength.

TABLE 5

RECOMMENDED CONDITIONS FOR THERMAL TREATMENT OF WROUGHT ALUMINUM ALLOYS

Thermal Treatments for Heat-treatable Alloys

Alloy	Annealing Treatment			Solution Heat Treatment ①, ②		Precipitation Heat Treatment		
	Metal Temp. Deg. F	Time Hours	Temper Designation	Metal Temp. Deg. F ③	Temper ④ Designation	Metal Temp. Deg. F ③	Time ⑤ Hours	Temper ④ Designation
11S	775 ⑥	2–3	11S–O	950	11S–T4	320	12–16	11S–T6
14S, Alclad 14S ⑦	775 ⑥	2–3	14S–O	940	14S–T4 ⑬	340	8–12	14S–T6 ⑧
17S	775 ⑥	2–3	17S–O	940	17S–T4	...	.....	....
						375 ⑨	11–13	24S–T81
24S, Alclad 24S ⑦	775 ⑥	2–3	24S–O	920	24S–T4 ⑬	375 ⑨	8–10	24S–T84 24S–T86
61S	775 ⑥	2–3	61S–O	970	61S–T4	320 350	16–20 6–10	61S–T6 61S–T6
62S	775 ⑥	2–3	62S–O	970	62S–T4	350	6–10	62S–T6
63S	775 ⑥	2–3	63S–O	970	63S–T4	350	6–10	63S–T6
						450 350	1–2 3–5	63S–T5 63S–T5
75S, Alclad 75S ⑦	775 ⑩	2–3	75S–O	870 ⑪	75S–W	250 ⑫	22–26	75S–T6

NOTES

①The time of heating varies with the product, the type of furnace and the size of load. For sheet heat treated in a bath of molten salt, the time may range from 10 minutes for thin material to 60 minutes for thick material. Times of several hours may be required in air furnaces because the metal comes to temperature less rapidly. A minimum of four hours is suggested for average forgings.

②The material should be quenched from the solution-heat-treating temperature as rapidly as possible and with a minimum of delay after removal from the furnace. Quenching in a large tank of cold water is preferred, although bulky sections, such as large forgings, usually are quenched in water at 140 to 212°F (140 to 160°F for 75S forgings) to minimize quenching strains.

NOTES—Continued

(3) The temperature specified should be attained by all portions of the load as rapidly as possible and should be maintained, with as little variation as possible, during the recommended time at temperature. Furnaces capable of maintaining the temperature well within plus or minus 10°F of that desired are readily available.

(4) These designations apply to material which has been heat treated by the user. A different designation may apply to material heat treated by the producer.

(5) The rate of cooling from the precipitation heat treatment is unimportant but should not be unduly slow.

(6) This treatment is intended to remove the effect of heat treatment and includes cooling at a rate of about 50°F per hour from the annealing temperature to 500°F. The rate of subsequent cooling is unimportant. The treatment recommended for 2S can be used to remove the effects of cold-work or partially to remove the effect of heat treatment if a fully annealed material is not required.

(7) Alclad sheet is heat treated under the same conditions as the core alloy but the shortest heat-treatment time consistent with securing the required properties should be used, and repeated reheat treatments should be avoided. Prolonged heating or repeated reheat treatments cause diffusion of alloying elements into the coating and impair the resistance to corrosion.

(8) For extrusions, the correct temper designation is -T62.

(9) Cold-working subsequent to the solution heat treatment and prior to the precipitation treatment is necessary to secure the required properties.

(10) Should be followed by heating for about 6 hours at about 450°F if material is to be stored for an extended period of time before use.

(11) Sheet may also be heat treated at higher temperatures (up to 925°F) if desired.

(12) A two-stage treatment comprising 4 to 6 hours at 210°F followed by 8 to 10 hours at 315°F or 2 to 4 hours at 250°F followed by 2 to 4 hours at 325°F may be used for sheet.

(13) For extrusions, the correct temper designation is -T42.

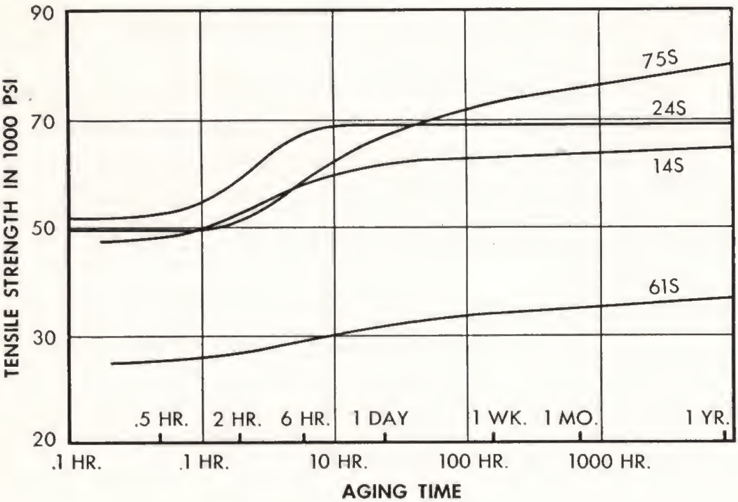

Figure 2—Aging time showing increase in tensile strenth.

REHEATING THE HIGH STRENGTH ALUMINUM ALLOYS FOR HOT-FORMING

The high-strength wrought alloys in the heat-treated and artificially aged conditions have limited formability. For this reason, it is recommended that all severe forming operations be made on -O temper sheet, which can be subsequently heat treated and aged to the desired temper. Less severe forming operations may be performed on products in the naturally aged temper. If it is not convenient or possible to form the article in any but the artificially aged temper, some increase in formability can be obtained by forming the article at an elevated temperature. Generally, the higher the temperature, the greater the formability will be. Too high temperatures cannot be used, however, as considerable loss in strength may occur. The times and temperatures reported in Table 6 may be used as a guide during reheating for hot-forming. Under these conditions of time and temperature, the losses in strengths as a result of reheating generally will not exceed about 5 per cent. It is to be understood that these are maximum times

of reheating and that, in most cases, equal formability will be obtained with shorter periods of heating.

Reheating of naturally aged products of 14S and 24S is not recommended unless it is definitely known that the part will be artificially aged. Generally, any reheating of sufficient value to materially improve the formability will lower the resistance to corrosion to an undesirable degree. An exception to this statement may be made for alclad sheet.

TABLE 6

MAXIMUM REHEATING TIMES FOR THE FORMING OF HEAT-TREATABLE ALLOYS AT VARIOUS TEMPERATURES

Maximum Reheating Times①

Temperature	61S–T6	75S–T6	14S–T6	24S–T81	24S–T86
500°F	No	No	No	No	No
450	5 min.	No	To temp.	5 min.	5 min.
425	15 min.	To temp.	To temp.	15 min.	15 min.
400	30 min.	5-10 min.	5-15 min.	30 min.	30 min.
375	1-2 hrs.	30-60 min.	30-60 min.	1 hr.	1 hr.
350	8-10 hrs.	1-2 hrs.	2-4 hrs.	2-4 hrs.	2-4 hrs.
325	50-100 hrs.	2-4 hrs.	8-10 hrs.	....	....
300	100-200 hrs.	10-12 hrs.	20-50 hrs.	20-40 hrs.	10-20 hrs.

①Also apply to alclad products.

ALCLAD ALLOYS

It will be noted in the table of mechanical properties (Table 3, page 10) that some of the alloys are designated as "alclad." This designation is used for those materials, usually in the form of sheet or plate, which consist of a core of the designated alloy with coatings on either one or both sides of another alloy of pure aluminum metallurgically bonded to the core. Alclad 24S sheet, for example, consists of a 24S core with a coating of high purity aluminum on each side while Alclad 14S is made up of a 14S core with coatings

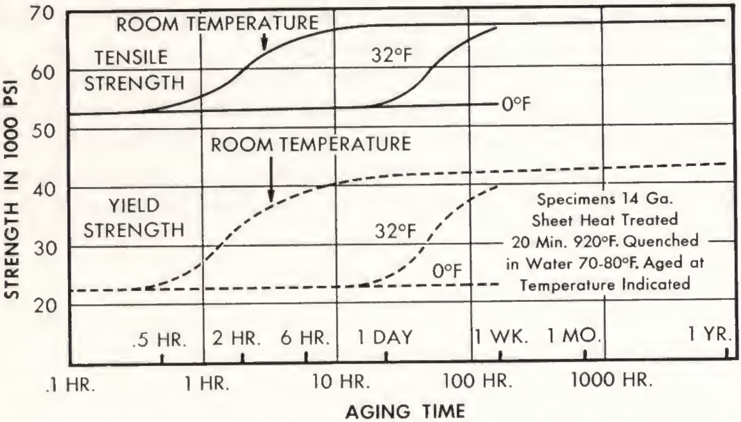

Figure 3—Aging of 24S showing increase in tensile strength and yield strength at various temperatures.

on each side of 53S alloy. The coating on Alclad 75S is 72S, an alloy containing about 1 per cent zinc.

The alclad coating alloys not only have good resistance to corrosion, but also provide electrolytic protection to the core alloy wherever it is exposed at cut surfaces or deep scratches.

The alclad materials can be formed over slightly smaller radii than are required for the core alloy, but because the surface alloy is not so hard as the core, they are more easily scratched or abraded.

OTHER FACTORS IN SELECTING ALLOYS

In the selection of an alloy, factors other than forming characteristics and strength requirements must be taken into consideration. In airplane construction, for example, some parts which are not subject to corrosive conditions may be made of the bare sheet while other parts may be made of alclad sheet in order to obtain added resistance to corrosion. Containers, such as shipping drums, which are used for transporting chemicals must have not only the required strength but also must resist the action of the particular chemical to be handled. In such cases, special tests are required to determine which alloy is the most

suitable. It is necessary, therefore, for each fabricator to study carefully the service conditions of the finished product in order to select the alloy best suited for the application.


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BLANKING AND PIERCING

BLANKING

In preparing sheet aluminum for subsequent forming operations, the blank size must be accurately developed and carefully cut to shape.

The most common method of blanking for high production work is the use of punch and die tools in single-action presses. The tools for blanking aluminum are similar to those used for other metals. The main differences to be observed have to do with type of tool steels to be used, clearances between punch and die, lubrication and maintenance.

The punch is usually made of annealed tool steel, while the die should be made of hardened tool steel. The faces of both the punch and die must be ground to keep the cutting edges sharp, or burrs will result on the edge of the blank. When it is desirable to keep the load on a blanking press at a minimum, the top of the die surface may be ground so that the shearing edge around the die opening is not on a single plane. By tilting the die on opposite angles during grinding, two opposite high points may be ground on its top. These high points should differ from the low points by at least half the thickness of the material to be blanked, preferably the full thickness. If the blanks must be kept flat, the punch should be ground flat regardless of high and low points on the die surface.

TOOL DESIGN

The correct amount of clearance between the punch and die is determined by the type of alloy and thickness of the sheet to be blanked. If the clearance is too great, the blank will be "broken out" rather than sheared. If too small a clearance is used, the tools will be subjected to excessive strain. Improper clearance either way produces rough blanks, is hard on tools, and requires more power for the operation of the press. In general, the clearance (the difference between die and punch diameters) should be equal to one-tenth the thickness of the sheet being punched. The blanking operation should produce a true cutting action for about one-third of the metal thickness and fracture thereafter.

The walls of the die opening should be tapered away from the cutting edge three-fourths of a degree to permit the blank to drop through easily. Since there is a tendency for the scrap to cling to the punch on the upstroke, a stationary stripper may be attached to the die or a spring stripper attached to the punch, as shown in Figure 4, below.

It is important that the designer lay out the work to insure the least possible waste. Table 7, page 25, shows the conventional scrap allowance for various gages and sizes of blanks.

There is danger of shearing or scoring the punch unless some means is provided for aligning it accurately with the die. The time required to set up the equipment, as well as the tool maintenance cost, can be considerably lessened by mounting the punch and die in a leader pin die-set.

LUBRICATION

Both the sheet to be blanked and the cutting edges of the tool should be generously lubricated to keep tool maintenance costs down and to produce smooth-cut blanks. A medium grade engine oil plus a little fatty oil diluted with kerosene is commonly used.

The sheet may be lubricated by hand brushing, or by passing it through oiling rolls or saturated felt pads. Thin coiled sheet is usually fed into the press automatically on feed rolls. The metal, before entering the die, passes through the lubricating equipment.

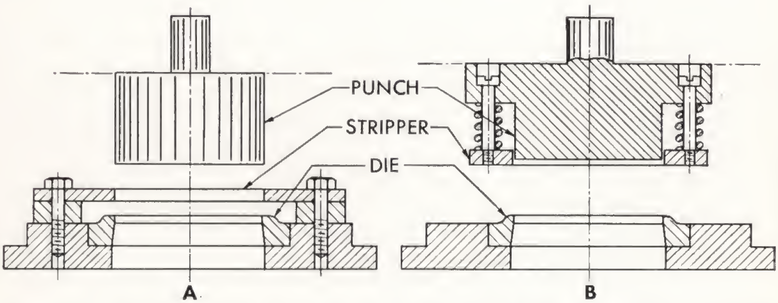


Figure 4—Scrap may be removed from the punch by stationary or spring strippers.

TABLE 7

SCRAP ALLOWANCES FOR BLANKING

Gage	Blank Size, Inches	Scrap Allowance, Inch
No. 28 (0.013 in.) to No. 15 (0.057 in.) incl.	0 to 10 incl.	1/16
	10 to 20 incl.	3/32
	20 to 30 and over	1/8
No. 15 (0.057 in.) to No. 12 (0.081 in.) incl.	0 to 10 incl.	3/32
	10 to 20 incl.	1/8
	20 to 30 and over	5/32
No. 12 (0.081 in.) to No. 8 (0.128 in.) incl.	0 to 10 incl.	1/8
	10 to 20 incl.	5/32
	20 to 30 and over	3/16

OTHER METHODS OF BLANKING

Rubber Pad: The rubber pad method of shearing blanks has more recently been developed in the aircraft industry. The metal is placed over small dies which have been carefully laid out in such a manner as to use the metal most economically. The bottom of the ram, covered with a heavy rubber pad, comes down and as the rubber which is confined to prevent lateral flow adjusts itself to the shape of the various dies, it blanks out the aluminum pieces. This flexible operation is especially suited to the production of parts in relatively small quantities and saves the construction of costly die sets.

Shears: Guillotine shears, either power or foot operated, may be used for straight cuts only. If the shears are provided with a mechanical hold-down, a clearance of one-tenth to one-eighth of the thickness of the sheet is required. A low rake or shearing angle on the upper shear knife will aid in reducing twist in thin stock.

When the quantity is too small to justify a special blanking die, circular blanks may be cut by circle shears. The unishear may be used to cut either straight or curved lines to a pattern and if sheets are thicker than the unishear can handle, the nibbler may be used to cut out a blank to any pattern.

Band Saws: Band saws are used quite satisfactorily for preparing aluminum sheet and plate for subsequent forming opera-

tions. High blade speeds, in the range 2,000 to 5,000 feet per minute, are desirable for best results. Spring-tempered blades which are hardened throughout are recommended for sawing sheet while flexible back-type blades with hard teeth should be used for heavy plate. The width of the blade used should be based upon the thickness of sheet or plate and the radii of any inside or outside corners which are to be cut.

Within practical limits, the pitch of the teeth should not exceed the thickness of the material to be cut. Blades having relatively coarse teeth and deep, smooth, rounded gullets are desirable to provide ample space for chips to form and escape. Use of a liquid or grease-type cutting compound improves cutting efficiency and increases saw blade life.

Routers: The router machine is a more recent development for cutting stacks of sheet metal blanks. The cutter is a small diameter milling tool which turns at high speed on a vertical axis, and is guided by a template clamped to the work. The resulting edges are smoother than those of sawed blanks. The versatility and accuracy of these machines and the economy with which templates can be produced have made routing a popular method for cutting odd-shaped blanks.

TRIMMING

A trimming operation is required after most forming operations and may be accomplished by several methods, similar to those used for preparing the blank. The punch and die method is quite common and the proper clearances are essentially the same as those used for preparing the blanks. Considerable ingenuity is required to dispose of the excess metal cut from shaped articles which must be trimmed on all sides.

When trimming round shapes, the lathe is often used. The article to be trimmed is placed on a chuck, and the trimming operation performed by an automatic cut-off tool. Trimming may also be done by a hand tool, held against a steady rest.

The band saw, circular saw and routing machine are also used for trimming, choice of method depending on the production schedule, shape of the part, and the accuracy required.

PIERCING AND PERFORATING

Piercing is fundamentally the same as blanking, but is the term that is used when the part cut out is scrapped. If the holes are quite small and close together the process is called perforating. Either single-action presses or horn presses may be used for piercing and perforating, and the tools consist of the usual punch and die. In piercing, the shape of the hole conforms to the punch. The die is ground flat in order not to distort the work, and the punch may be ground with high and low points.

When a gang punch is used, it is much easier on the press to "step" the individual punches slightly so that they do not all enter the metal at the same time. If the punches are small and close together, stepping will also prevent "crowding" the metal and pushing some of the delicate punches out of line. The gage of the metal determines how much should be ground off the punches. Each step should be a little less than the thickness of the metal, as too much difference produces a jerky operation. The longer punches should normally be on the outside, surrounding smaller ones. Large diameter punches, however, should always be longer than those of small diameter, regardless of position. This prevents deflection and chipping of the smaller punches.

For piercing, the clearance (the difference between punch and die diameter) should not be more than 5 per cent of the thickness of the metal. If the clearance is too great, the slugs will be lifted with the punch on the return stroke. The punches should be lubricated; light oil or kerosene applied with a brush may be used.

GENERAL SHEET METAL PRACTICES

THE EQUIPMENT found in most modern sheet metal shops can be readily used in forming aluminum alloys. It is important, of course, that the parts of the machine which come into direct contact with the aluminum are kept clean and free from rust, scale, chips or imperfections that would mar or scratch the finished parts. Operations such as bending, rolling, flanging, beading, curling, crimping, or hammering can be performed manually or with mechanical devices.

Bending is the basic operation in most sheet metal work. During a bending operation the metal on the outside of the bend is stretched while that on the inside of the bend is compressed. If breakage or severe strain occurs, a larger radius must be used, or the alloy or the temper must be changed to provide material with better bending characteristics.

Table 8, page 30, shows bend radii which have been used successfully on a variety of types of forming equipment for the different aluminum alloys and tempers. Shorter radii can be used under favorable conditions, but use of the smallest radius shown to be successful in a tool tryout is apt to cause difficulty in production because of variations in material, tool setup, etc.

SPRING-BACK

The problem of "spring-back" is encountered in most forming operations. Upon release of the forming pressure, the member springs back as the residual stresses come into balance. The metal should be formed beyond the required angle so that when spring-back occurs the desired angle is attained. Another method of controlling spring-back is to bottom the forming tool in the die. When a sheet of metal is to be formed into a channel shape in one operation, several methods may be used to compensate for spring-back. Figure 5, on page 31, shows how tapering the punch and using a rubber pad will form the sides beyond 90°. Figure 6, on page 32, shows how arching the base in the channel will also draw the sides to the desired angle.

TABLE 8

TYPICAL RADII FOR 90° COLD BEND ALUMINUM AND ALUMINUM ALLOY SHEET

Typical bend radius varies with nature of forming operation, type of forming equipment, and design and condition of tools. *Minimum working radius for given material or hardest alloy and temper for a given radius can be ascertained only by actual trial under contemplated conditions of fabrication.*

Alloy and Temper	Approximate Thickness (Inches)					
	0.016 1/64	0.032 1/32	0.062 1/16	0.125 1/8	0.188 3/16	0.250 1/4
2S-O	0	0	0	0	0	0
2S-H12	0	0	0	0	0–1	0–1
2S-H14	0	0	0	0	0–1	0–1
2S-H16	0	0	0–1	½–1½	1–2	1½–3
2S-H18	0–1	½–1½	1–2	1½–3	2–4	2–4
3S-O	0	0	0	0	0	0
3S-H12	0	0	0	0	0–1	0–1
3S-H14	0	0	0	0–1	0–1	½–1½
3S-H16	0–1	0–1	½–1½	1–2	1½–3	2–4
3S-H18	½–1½	1–2	1½–3	2–4	3–5	4–6
4S-O	0	0	0	0	0–1	0–1
4S-H32	0	0	0	0–1	0–1	½–1½
4S-H34	0	0	0–1	½–1½	1–2	1½–3
4S-H36	0–1	½–1½	1–2	1½–3	2–4	2–4
4S-H38	½–1½	1–2	1½–3	2–4	3–5	4–6
B50S-O	0	0	0	0	0	0–1
B50S-H32	0	0	0	0	0–1	½–1½
B50S-H34	0	0	0	0–1	½–1½	1–2
B50S-H36	0–1	0–1	½–1½	1–2	1½–3	2–4
B50S-H38	½–1½	1–2	1½–3	2–4	3–5	4–6
52S-O	0	0	0	0	0–1	0–1
52S-H32	0	0	0	0–1	0–1	½–1½
52S-H34	0	0	0–1	½–1½	1–2	1½–3
52S-H36	0–1	½–1½	1–2	1½–3	2–4	2–4
52S-H38	½–1½	1–2	1½–3	2–4	3–5	4–6
24S-O ①	0	0	0	0	0–1	0–1
24S-T3 ①②	1½–3	2–4	3–5	4–6	4–6	5–7
24S-T36 ①	2–4	3–5	4–6	5–7	5–7	6–10
61S-O	0	0	0	0	0–1	0–1
61S-T4	0–1	0–1	½–1½	1–2	1½–3	2–4
61S-T6	0–1	½–1½	1–2	1½–3	2–4	2–4
75S-O	0	0	0–1	½–1½	1–2	1½–3
75S-T6	2–4	3–5	4–6	5–7	5–7	6–10

① Alclad sheet can be bent over slightly smaller radii than the corresponding tempers of the uncoated alloy.

② Immediately after quenching, this alloy can be formed over appreciably smaller radii.

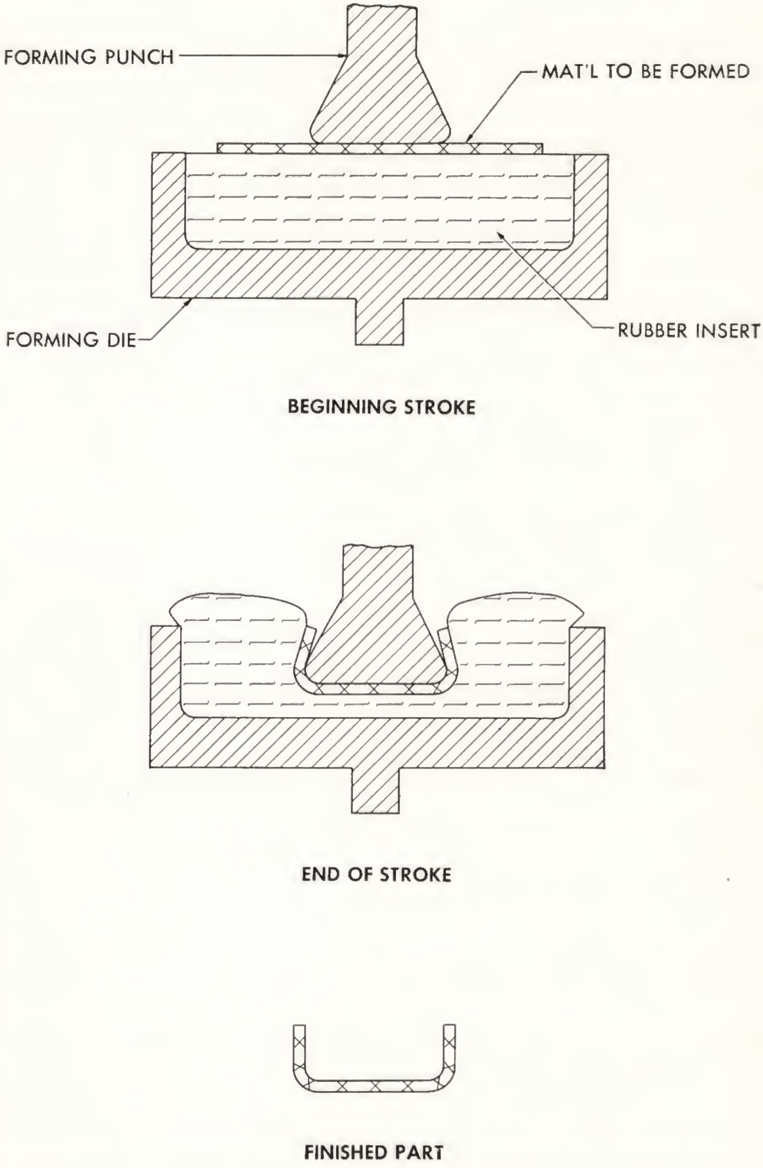


Figure 5—Tapered punch and rubber pad compensate for spring-back.

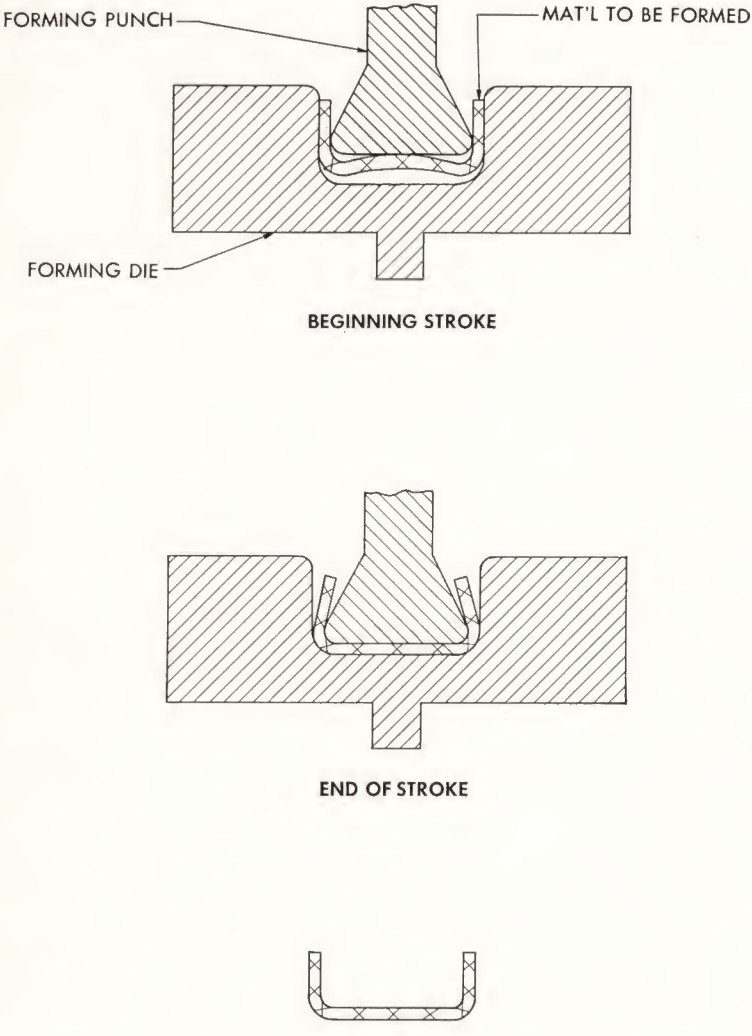


Figure 6—Arching the base in the channel draws the sides to the desired angle.

In the alloys with low yield strength, spring-back is negligible. On the other hand, alloys which have higher yield strengths exhibit considerably more spring-back. In the final analysis, "cut and try" methods are most satisfactory for determining how to compensate for spring-back.

TEMPER SELECTION

When such aluminum alloys as 2S, 3S, 4S and 52S are formed, care must be taken to select a temper of material commensurate with the design strength requirements and the desired minimum bend radii. The more difficult forming operations may require the selection of annealed, or O, tempers while less severe operations may often be satisfactorily performed on material in one of the harder tempers.

While the heat-treatable alloys require generous bend radii when being formed in the fully heat-treated temper, these alloys can be bent over very small radii if they are worked in the annealed condition. The desired high strength can then be obtained by heat treating the formed part, although this procedure may introduce some problems because of distortion during quenching. This distortion can largely be avoided, if the smallest possible bend radius is not essential, by forming them in the T4 or the W temper and then aging the formed part to obtain the desired properties.

FORMING EQUIPMENT

The aluminum alloys may be formed in the ordinary folding brake, or bar folder, using approximately the same technique as is used on other metals. The bend radius is controlled by the blade location.

The power brake with the proper tooling will produce a wide variety of shapes. The tools most commonly used are "V" dies with punches having suitable radii.

When a limited quantity of relatively thin metal parts must be formed, a rubber die may be used. In this process, a block of rubber is restrained in a steel channel section. The work, as it is

forced into the rubber, assumes the shape of the punch. This method is sometimes useful in forming multiple beads or embosses.

Edging, beading or curling rolls are often employed to produce a beaded or half-round edge. The rolls employed are usually specifically designed to meet the requirements of the job and are designed in pairs so that the female roll fits the driven shaft.

Many complicated shapes can be formed by utilizing rolled molding machines in which the material travels through successive rolling operations in a single machine.

Aluminum may be readily formed by hand hammering although this method is generally used for sample work or for very small quantities.

Power hammers are often used to smooth out irregularities left from previous operations, as well as to "set" the final shape. Power hammering is sometimes utilized to stretch the metal when it is necessary to increase slightly the size of a part.

Curved surfaces, or cylinders, may be fabricated by roll forming. In producing cylinders by this method, a flat area, approximately equivalent to the distance between the lower front and the back roll, is encountered. This flat area may be minimized by preforming the ends of the sheet to the proper radius before the sheet is fed into the forming rolls. The rolls used on aluminum must be kept clean. It is sometimes advisable to protect the sheet during the rolling operation with heavy paper.

DRAWING

EQUIPMENT

THE drawing of aluminum is done on the same type of equipment that is used for other metals. The shape and thickness of the blank, depth of the drawn item, and the alloy and temper of the sheet are some of the factors that influence the type, size and capacity of the press to be used.

Many shallow draws are made on single-action presses because of the high speed at which they can be operated. On the larger presses, speeds may be as high as 60 strokes per minute while small presses run as high as 400 strokes per minute. If no blankholder is used in the drawing operation, the thickness of metal must be sufficient to avoid wrinkling. When a blankholder is required, an air cushion is sometimes attached to the press, or springs are built into tools to provide the necessary blankholder pressure to avoid wrinkling.

Deeper draws require the double-action press which has an outer ram to which a blankholder is attached and an inner ram to which the punch is attached. These two parts of the press may be activated mechanically or by hydraulic pressure. In drawing a shell, the outer ram with the blankholder attached descends first and exerts pressure on the outer edge of the blank. The inner ram to which the punch is attached then decends and forces the metal into the die. The pressure on the blankholder must be adjusted to permit the blank to slip and at the same time prevent any wrinkles from forming. If the blank is held too tightly it will break. It is always necessary to make a very careful adjustment of the blankholder pressure so that a smooth shell of uniform metal thickness will be obtained.

ALLOYS AND TEMPER OF SHEET FOR DRAWN ITEMS

The proper temper of the common alloys is determined by the article to be drawn. For severe draws, the annealed (O) sheet is used, but for less severe draws the intermediate tempers or even full hard temper may be used.

When the heat-treatable alloys are used, severe draws are usually made from annealed sheet. For less severe draws, sheets of Alclad 14S in the W or T4, and 61S in the T4 temper can be used. In case of 75S and Alclad 75S as well as 24S and Alclad 24S these draws are often made in the as-quenched or W temper. Parts drawn from annealed or as-quenched (W) sheet can then be placed in the T4 or T6 condition by suitable treatments.

DESIGN OF TOOLS

The tools used in drawing aluminum may be divided into four parts: die, knockout, blankholder, and punch. Although these are similar to those used for other metals, the designer should take into account differences in amount of reduction per draw, radii on the tools, and change in metal thickness.

During drawing, the metal strain hardens and changes from the annealed to the harder tempers with an increase in mechanical properties as shown in Table 9. It therefore becomes less workable, and the reductions per draw in successive draws must be decreased. For deep-drawn cylindrical shells in the annealed, or O temper, the reductions in diameter per draw should be approximately as shown in Table 10. Caution should be exercised to avoid making the operations too critical; otherwise the scrap loss may exceed the expense saved in tooling.

Since there is little change in hardness after the third draw, the 15 per cent value given in Table 10 is suitable for the fourth and subsequent draws. While the values given in this table may be varied, they should not be exceeded. In fact, for harder alloys, such as 52S, in which the increase in strength is greater, the values given in the table may have to be reduced by as much as 0.10 D for the first draw and 0.05 D for succeeding draws.

The punch radius should usually be held to a minimum of four times the thickness of the metal. The radius on the die should be no less than four times and no more than fifteen times the thickness. If the radius is too small, the resistance to the flow of metal may cause fractures. If the radius is too large, wrinkling may occur.

The drawing tools should be so designed that the original thickness of the sheet is changed very little. This practice differs from

TABLE 9

EFFECT OF DRAWING ON MECHANICAL PROPERTIES

Alloy	No. of Draws	Tensile Strength, Psi	Yield Strength, Psi	Elongation, Per Cent in 2 In.
3S	0	16,000	6,000	30.0
	1	18,740	16,700	11.0
	2	22,140	20,800	9.0
	3	23,710	21,900	8.0
	4	24,240	22,300	7.5
52S	0	29,150	14,200	27.0
	1	34,390	31,600	6.0
	2	39,710	37,100	5.0
	3	42,680	38,600	5.5
	4	43,750	36,100	6.0

TABLE 10

REDUCTION IN DIAMETER FOR DEEP SHELLS

Operation	Suggested Reduction
Blank (D)	
First draw (D_1)	0.40D
Second draw (D_2)	$0.20D_1$
Third draw (D_3)	$0.15D_2$
Fourth draw (D_4)	$0.15D_3$

that for brass and steel sheet, which may be reduced in thickness as much as 50 per cent. For this reason it is often necessary to redesign tools used for brass and steel when they are to be used for drawing aluminum alloys.

MATERIAL FOR DIES

Drawing tools are made from cast iron, high-grade alloy steel, carbon steel or with cemented tungsten carbide inserts, depending on such factors as the type of draw, the alloy of sheet to be formed, the final finish desired, and the quantity to be made.

Cast-iron tools have been widely used for limited production where it is necessary to keep tool costs at a minimum. The saving

in this case is obtained both in the cost of the material and in the cost of machining. Cast-iron tools are also suitable for larger quantities when the requirements for surface finish on the drawn parts are not exacting. However, the presence of scratches and surface imperfections resulting from their use increases finishing costs if a highly polished surface is desired. While somewhat higher in cost, a number of grades of alloy cast iron are sometimes used because they give better results.

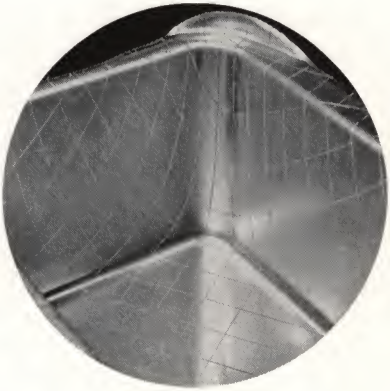
On large production runs where the extra tool cost is justified, high-grade alloy tool steels have been found to give best results. They also are used for drawing shells from hard alloys and on work where scratches must be kept at a minimum. Oil hardening steels usually are used to obtain the maximum hardness with minimum distortion during treatment.

Intermediate in cost and performance between cast iron and high-grade alloy steels are regular carbon steels with 0.6 to 1.10 per cent carbon.

It is very important to have a polish on the working surfaces of tools used for forming aluminum; especially on drawing tools. Fine scratches or imperfections on the tool's working surfaces can retain particles of dirt and foreign material which will produce scratches on the formed aluminum. A more serious effect of poorly polished tools is that the resistance to metal movement over such surfaces is much greater. This condition may become a prime factor in causing a part to fail during forming.

FLOW OF METAL DURING DRAW

Drawn shells usually are rectangular, cylindrical or hemispherical, although odd shapes are not uncommon. In a rectangular shape, as shown in the circular drawing in Figure 7, the greatest flow of metal occurs at the corners. This flow must be controlled to prevent wrinkles and fractures. Provision for this factor can be made by varying the draw radius which should usually be not less than six times the sheet thickness and preferably not less than three-eighths inch. Dimensions of the original blank must be such that there is enough metal to obtain the desired shell. The shape of the blank naturally depends on the shape of the item drawn. Figure 8, page 43 shows typical first



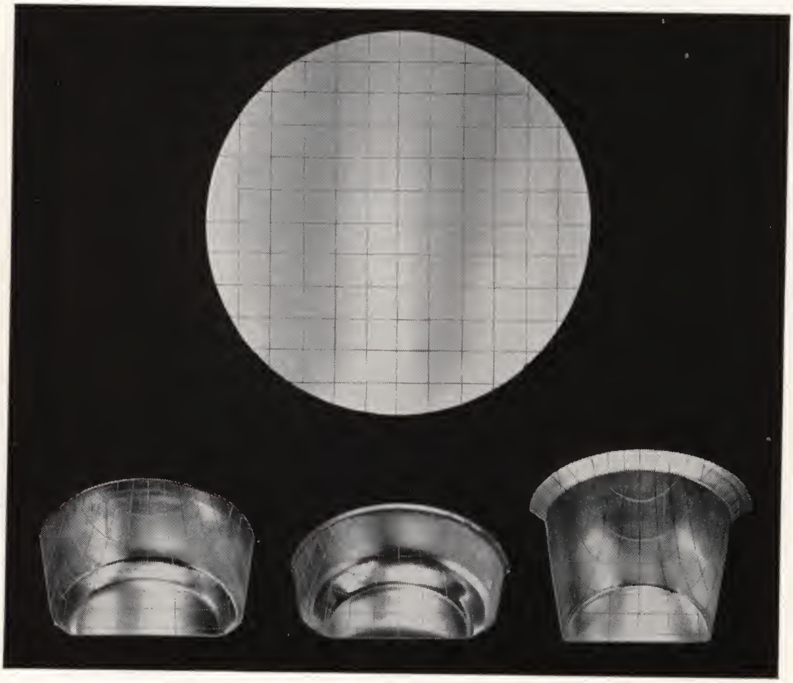


Figure 7—Flow of metal in these drawn shells is indicated by lines scribed on the blanks.

and second operation shells and the blank for a rectangular shell. Die dimensions for the various draws are given in Table 11.

TABLE 11

DIE DIMENSIONS FOR DRAWING RECTANGULAR SHAPES

First draw	Add 2.2 times blank thickness to punch dimension
Second draw	Add 2.2 times blank thickness to punch dimension
Final draw	Add 2.0 times blank thickness to punch dimension

The flow of metal in a drawn cylindrical shape is illustrated at the bottom of Figure 7. Notice that although the shapes of the original squares have been changed considerably, their area is about the same, indicating there has been very little change in thickness. Figure 9 shows the sequence of drawing operations, and Table 12 gives the die dimensions.

TABLE 12

DIE DIMENSIONS FOR DRAWING CYLINDRICAL SHAPES

First draw	Punch diameter plus 2.2 times thickness of blank
Second draw	Punch diameter plus 2.3 times thickness of blank
Third and succeeding draws	Punch diameter plus 2.4 times thickness of blank
Final draw of tapered shells	Punch diameter plus 2.0 times thickness of blank

Metal drawn into the form of a dome or a hemisphere has a tendency to wrinkle, especially in the thinner gages. If such a shape is to be made in one draw, the ratio of the inside diameter of the drawn shell to the original metal thickness should be kept below 200; otherwise wrinkles will usually form. If two draws are used to form the shell, it is important that the first shell have sufficient metal at the proper location so that the second shell will draw without fracturing or wrinkling. Such drawing operations are illustrated in Figure 10.

CHOICE OF LUBRICANT

A lubricant for drawing work has two important functions. First, it allows the blank to slip readily between the blankholder

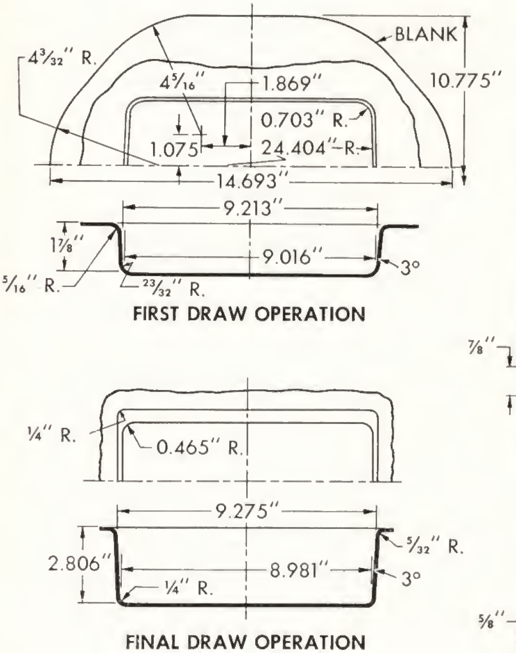
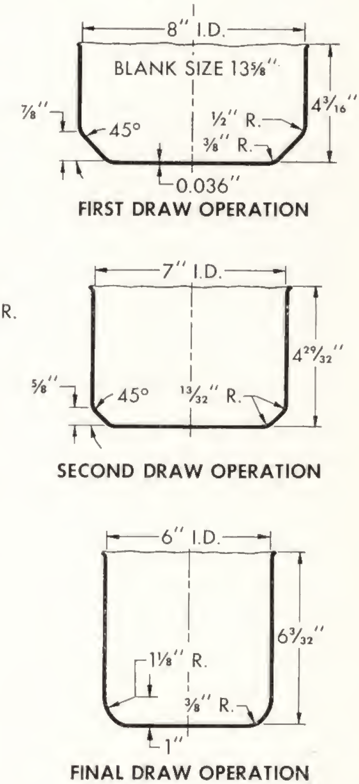


Figure 8 (*Above*)—Typical first and second operation shells for an aluminum pan.

Figure 9 (*Below*)—Sequence of drawing operations for a cylindrical shell.



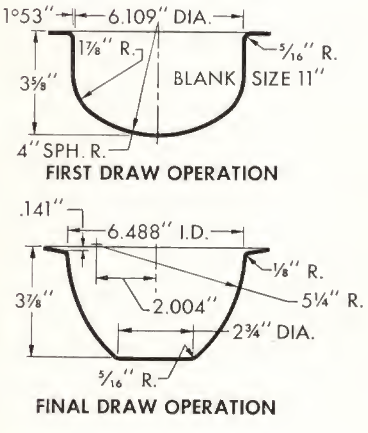


Figure 10 (*Left*)—Procedure for drawing a bowl-shaped shell.

and the die. Second, it prevents scratching and galling while this movement takes place. Mineral oils or compounded mineral oils are most often used. Water-soluble drawing compounds have been found less satisfactory. Some of the oils that have proved suitable in production operations are the following:

Light draws	Light lubricating oil
Medium draws	Medium lubricating oil
Severe draws	Heavy lubricating oil or 50 per cent mutton tallow and 50 per cent paraffin mixtures
Very severe draws	30 per cent mutton tallow and 70 per cent paraffin mixtures

It should be remembered that proper choice of lubricant in a particular shop is a matter of experience and depends on the tool design, tool material and finish, and sheet thickness. Cast-iron and low-carbon-steel tools require a heavier lubricant to prevent scratching than do hardened steel tools. The greater the reduction per draw and the sharper the radii, the heavier must be the lubricant to allow the blank to slip into the die. Thick sheet requires a heavier lubricant than thin sheet. It is general practice to use mutton tallow and paraffin when drawing thick sheet.

OTHER MECHANICAL FORMING METHODS

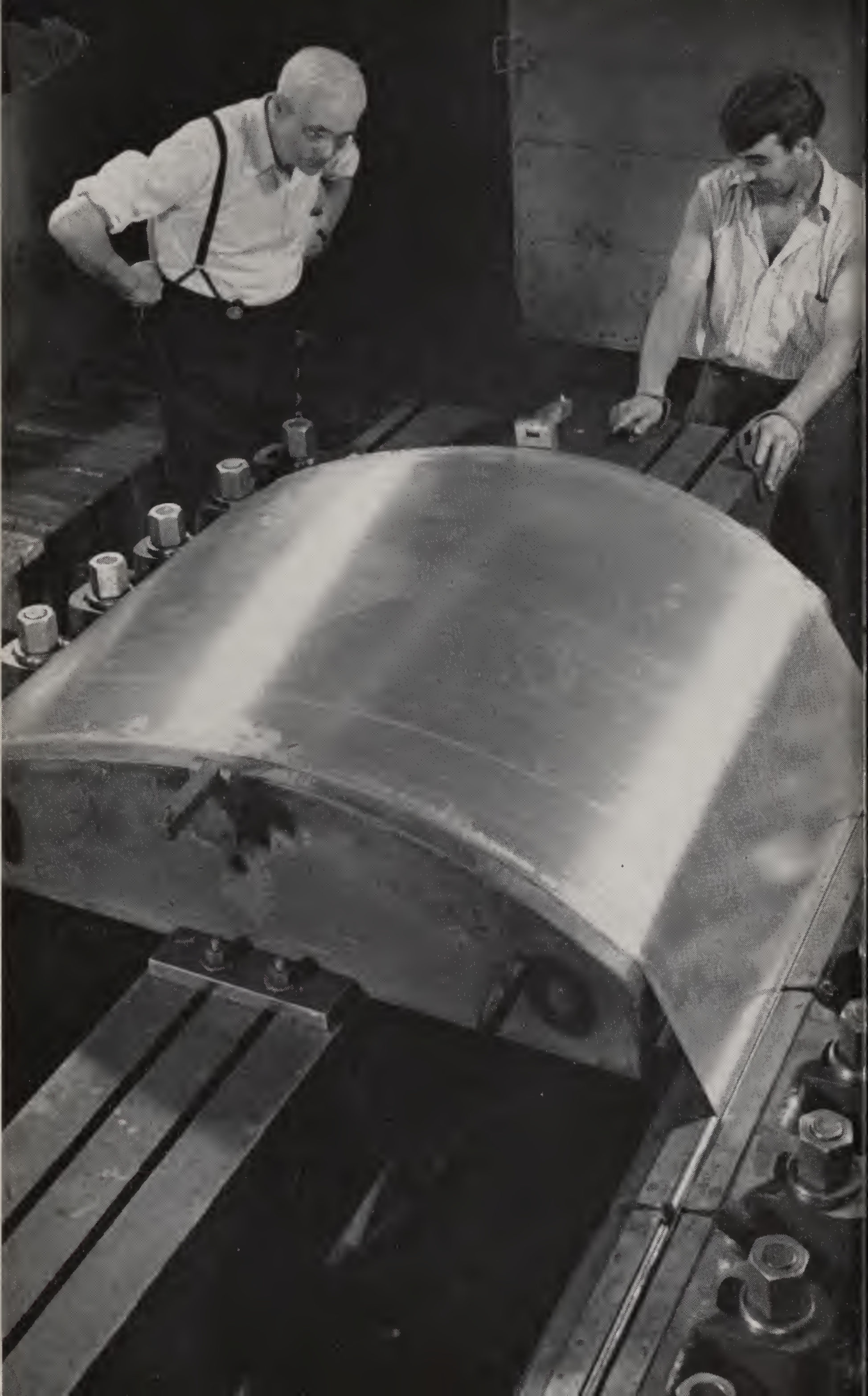
STRETCHING

In this operation, the edges of the sheet are clamped tightly while a punch of the desired shape is pushed against the sheet by means of a hydraulic ram. The metal is actually stretched over the punch and thus takes the required shape. This method of forming can be used for making long sweeping contours where sharp radii are not used and where compound contours are required. Its advantages are lower tool cost and less spring-back. Tools can be of any acceptable tool material which would be dictated by the severity of the forming operation and the economics of the job. Lubrication is generally desirable between the punch and the metal, and frequently it is possible to use a rubber sheet to effect slippage between the punch and the metal.

Molding and extrusions can also be shaped by this method and it has proved very advantageous for a number of applications. Instead of clamping the ends solidly, as in the case of sheet, they are clamped into jaws attached to air or hydraulic cylinders. A variation in pressure can be applied on these cylinders to obtain a satisfactory shaped part without the formation of wrinkles. It might be necessary in some cases to utilize a mandrel to support normally unsupported sections of the molding or extrusion being formed.

DROP HAMMER

Drop hammers are especially suitable for small production runs, since the dies and punches are inexpensive and easily made from wood or low melting alloys. They can, however, be adapted to large production, in which case dies of steel are used. The parts made on drop hammers usually are shallow and have liberal radii. In many instances, coining may be combined with forming in drop hammers. On shallow parts, sharp lines can be produced because of the sudden impact obtained with the drop hammer.



FORMING WITH HYDRAULIC MEDIUM

In many cases it is possible to employ a hydraulic method to draw or form metal. This method generally uses a die and a blankholder with the hydraulic medium used as a punch or to actuate the punch. The hydraulic medium in the first method acts directly on the metal while in the other the hydraulic medium is contained by a rubber sheet that acts against the metal. In addition to drawing metal, these methods are adaptable to expand a drawn shell when encased in a contour die. The expansion can be distributed over the entire shell or localized to provide an offset. It is important to note that the typical elongation for aluminum or an aluminum alloy cannot be used for directly calculating the allowable expansion of a shell by these methods.

FORMING WITH RUBBER

Reference has previously been made to the rubber pad method of blanking. This method is also adaptable to forming operations where deformation of the metal is very slight. The metal blanks to be formed are placed on dies lying on the bed of the press. A rubber pad covers the bottom of the ram and is displaced by the dies over which the metal is formed.

A process has recently been developed that can produce a deep-drawn shell on rubber. In this process, a rubber pad thicker than the depth of the shell is used with a type of a hydraulic cushion unit. The hydraulic unit is a part of the press bed and supports a punch in an inverted position similar to the setup of a single-acting air cushion press. Blankholder pressure is obtained by the resisting forces of the rubber pad and a blankholder supported by the hydraulic unit. Information previously listed with regard to deep drawing on steel tools is also applicable to the rubber pad process. In some cases, it is possible to exceed the previously recommended limits of per cent reduction and radii.

ROLL FORMING

Roll forming of aluminum or aluminum alloy sheet has been used successfully to produce architectural moldings, crate slats,

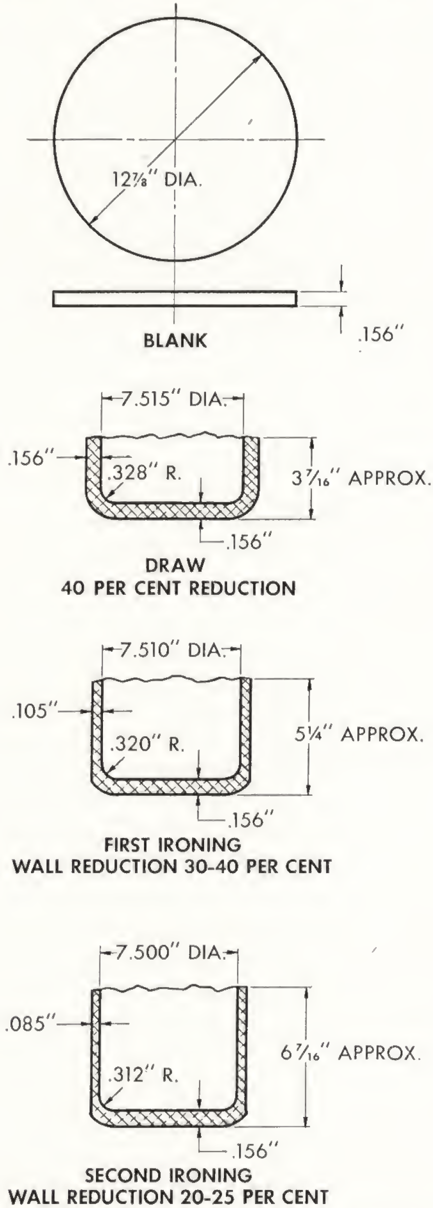


Figure 11—Ironing operation is used to produce shells with heavy bottom and thin sidewalls.

barrel chimes, house siding and many other sheet sections. Advantages of roll-forming sections are that relatively thin metal can be formed in this manner and that smaller radii bends can generally be formed than are indicated for 90° cold bends shown in Table 8, page 30. The intricacy of the section is dependent on the ingenuity of the roll designer. The length of a section to be formed is limited only by the length of the original stock. With flying cutoffs, the roll-formed section can be cut to a specified length. Tools generally made from a hardened tool steel are designed to overform the metal to allow for spring-back, the amount of which depends on the physical properties of the metal. Lubricants are not necessarily required for roll forming but are generally advantageous to minimize abrading and scratching the surface.

IRONING

The ironing operation is used to produce shells with a heavy bottom and thin sidewalls. The operations are shown in Figure 11.

The first operation is to draw a shell of the required diameter using the procedure as described under "Drawing."

The drawn shells should then be annealed following the practices shown in Table 4, page 13. The units should be brought to the annealing temperature as rapidly as possible in order to minimize the formation of coarse grains in that part of the drawn shell which has the critical amount of cold-work. The drawing lubricant must be removed from the shells prior to the annealing operation in order to avoid staining.

The wall reduction for the first ironing should be held between 30 and 40 per cent. The ironed shell should be cleaned and annealed the same as after drawing. In the second ironing, the wall reduction should be kept between 20 and 25 per cent.

The annealing operation serves two purposes:

1. Prevents breakage.
2. Keeps the variation of thickness in the sidewalls to a minimum.

If the variation of the thickness in the sidewall is not important, higher reductions can be made than those indicated above.

EMBOSSING, COINING AND STAMPING

EMBOSSING is the production of raised or projected figures or designs in relief on a surface, as at A and B in Figure 12, page 53. At A is a section through a stiffening rib and the open die used to produce it. Simple operations of this kind require relatively light pressures and can hardly be placed in the direct compression group. Such embosses frequently are incorporated in drawing and forming operations. Section B, Figure 12, page 53, illustrates a more complicated emboss requiring the use of a closed die. Embosses of this kind are definitely within the direct compression group and require comparatively high pressures to produce clear-cut outlines. Note that the thickness of stock is consistent throughout the section—the only factors causing a possible deviation being the mild stresses due to bending and stretching. It may be said that this uniformity of thickness is the identifying characteristic of the emboss.

The use of rubber to supplant the steel female embossing die has proved practical in many instances. The decoration of aluminum foil by passing it between a steel roll having the desired design cut in relief upon its periphery and a smooth rubber-faced contacting roll is but one example of its successful application.

Coining is a method by which the images or characters on a set of molds are impressed into the plane surfaces of a blank or a disk. At C in Figure 12, page 53, is an example of a coined blank, showing how the metal flows between the punch and the die and assumes a contour negative to that of the two faces. In the type of die shown, clearance is allowed for any flash that might occur around the circumference of the blank; when a completely closed die is used, danger may be encountered by over-gage blanks and the accidental feeding of double blanks. As a precautionary measure, such dies are often mounted on hydropneumatic pressure-equalizing cushions.

Semicoining is a combination of embossing and coining. It is a mechanical means of doing the work of the hand chaser by causing metal to flow from one part of the emboss to another. The die shown at D in Figure 12 is representative of such an operation and

is the same in all respects as the die at B except that the center emboss has a sharp profile. At E and F are enlarged sections which permit better analysis. It can be readily seen that the vertical sidewalls of section F are much thinner than those of section E. This is the result of a negative clearance between the punch and die, causing them to pinch at this point. The metal thus displaced is of sufficient volume to fill completely the sharp corners of the punch and die and produce the desired profile.

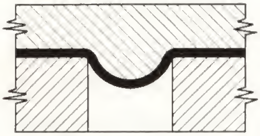
It is important that the tools and blanks for coining and embossing be kept free from foreign substances. The use of oil or other lubricant should be avoided. However, it has been found that in some classes of coining, the use of alcohol or another light lubricant is beneficial.

Stamping refers to the cut lines of letters, figures and decorations resulting from the impact of a stamp, having a comparatively sharp projecting outline, upon a smooth surface. At G in Figure 12 is a cross section of a typical stamping tool. Stamps such as that shown are usually cut to a depth of from 0.020 to 0.040 inch.

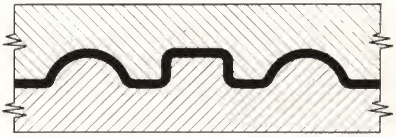
SIMPLE PRESS TOOLS USED

The press tools for embossing, coining and stamping are of simple construction. The usual tool consists of a punch and die which are mounted respectively on a punch holder and a die shoe. Except in stamping tools, it is always advisable to use a die set equipped with leader pins, in order to insure proper alignment of the punch and the die. In all coining and embossing tools, the punches and dies serve as forms for producing the desired designs. Aluminum being a comparatively soft metal, the impact of the press will cause it to flow into any minute imperfection in the face of the punch and die; it is important, therefore, that these parts be kept perfectly smooth and polished. Both the punch and the die should be made of a good grade of tool steel, and hardened so as to resist the excessive wear to which they are subjected.

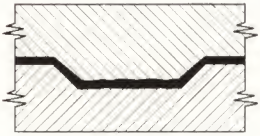
In the case of stamping tools, only the punch, on which the desired figure has been cut in relief, is hardened. The die—more correctly defined as the anvil—is smooth and usually made of a mild steel. Horn or single-action presses are often used for light



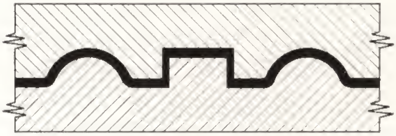
A—OPEN EMBOSSING DIE



B—CLOSED EMBOSSING DIE



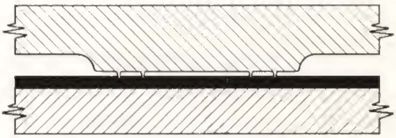
C—COINED BLANK



D—SEMI COINING DIE

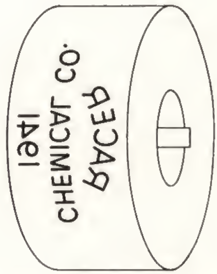
E—EMBOSSED SECTION

F—SEMI COINED SECTION



G—TYPICAL STAMPING TOOL

Figure 12—Typical compression operations. Press tools for work of this nature are of simple construction.



H—ROLLER STAMPING DIE

types of work. Frequently the stamping of numerals, trademarks, names and the like is effectively and economically combined with other manufacturing operations, such as drawing, forming and embossing. Stamps for such use are precisely made, and the depth is controlled by the use of shims of suitable thicknesses underneath the stamps.

Roller dies provide a very practical method for stamping. Section H, Figure 12, illustrates a roller die used in a marking machine. In flat stamping, the roll is driven over the stationary article and the "marking" is rolled into the surface. Similar stamps are used when the operation of marking cylindrical work is performed on a lathe or similar machine.

In stamping, the depth of penetration should be carefully observed. To prevent distortion and to keep the design from "showing through" on the stamped article, outline or open-faced stamps should be given preference as they do not displace as much metal as the broadfaced stamp.

Special knuckle-joint presses are built for coining and embossing. These machines are of rigid construction and take greater loads in proportion to their weight than any other press. They have short strokes and are designed so that the mechanical advantage of the knuckle joint results in intense pressures during the last portion of the stroke. Precision adjustment of the tool space is provided.

EFFECT OF MATERIAL USED

Controlling factors in the coining and embossing of aluminum, so far as the metal is concerned, are its malleability and ductility. The former is its characteristic to yield to compressive and impact forces, and the latter is a qualitative term referring to elongation produced by tension.

Within certain limitations, when a deforming force is removed from a piece of aluminum, it will regain its former shape. When this limit is passed, the metal takes a permanent set or only partially recovers. If, however, the deforming force is increased so as to produce a progressive deformation, then fracture will eventually result. It is the range between the limit of elasticity, which must be passed, and the ultimate strength, which must not

be exceeded, that constitutes the field for embossing.

Aluminum sheet is available in a variety of degrees of hardness from "soft" to "hard." Since temper affects its resiliency, or ability to absorb shock without permanent deformation, it is only logical that the soft or intermediate tempers, such as H12 and H14, or T4 in the case of heat-treated alloys, are preferable for embossing. A good rule to follow is to select a grade and temper with a high elongation and as low a yield strength and as high a tensile strength as consistent with the properties required by service conditions.

SPINNING

SPINNING is one of the oldest of the metalworking arts and has been used in making circular hollow ware for many years. While largely replaced by draw press forming for large scale production, it is still widely used when tool costs must be kept low, as well as in the manufacture of products which cannot be formed on a draw press because of size or design. Spinning is also commonly used in combination with drawing for economy in finishing and trimming operations.

In the spinning process, a lathe is used to rotate a circular metal blank or shell at high speed while it is pressed against a rotating chuck whose shape the blank is to take. The blank is forced against the chuck by means of suitable forming tools which are manipulated either by hand or mechanically. With an experienced operator, spun articles can be held to reasonably close dimensional accuracy and will be uniform in size and appearance.

Since the metal is formed over a chuck rotating in a lathe, the process is limited to symmetrical articles that are circular in cross section normal to the axis of rotation. Typical spun articles are cooking utensils, lighting reflectors, processing kettles, and ornaments of many different types.

ALLOYS

Commercially pure aluminum (2S alloy) is a ductile aluminum alloy which may be formed into quite complicated circular shapes by spinning. The other aluminum alloys are not spun so easily as 2S, although the aluminum-manganese alloy, 3S, because of its higher yield strength, is employed in the fabrication of a large number of spun articles and may be successfully spun cold. Occasionally 52S and the heat-treatable alloys are spun when higher strengths are desired in the finished article, but they must be annealed frequently during spinning or must be spun hot. Since cold spinning hardens the metal, it is desirable to start with an annealed blank unless the amount of spinning is small.

When it is necessary to heat the metal, a torch may be applied

to the partially spun article as it is rotated in the lathe. A soft pine stick rubbed against the metal will leave a brown char mark when the metal has been sufficiently softened by heating. The torch should be removed when this point is reached.

BLANKS

Blanks in thickness from 0.025 to 0.081 inch are usually spun by hand, although, with special care, metal thinner than 0.025 inch can be spun. Metal of greater thickness than 0.081 inch is usually spun by semimechanical or entirely mechanical methods.

The area of the starting blank should be equal to the surface area of the finished article. Since the blank decreases locally in thickness during spinning and, therefore, increases in area, this will allow for the necessary trimming. Because of this thinning effect, consideration should be given to the proper starting gage in order to finish with the required thickness.

LATHES

Spinning lathes used for aluminum are similar in many respects to the lathes used for woodworking, although they are of heavier construction. A larger headstock is necessary because of the heavy pressure exerted upon it. The bed of the lathe should be long enough to accommodate a wide range of lengths for a blank of given diameter unless, of course, only shallow shells are to be spun. The tailstock screw should have a coarse pitch to facilitate removal of the shell after spinning.

The process used for making spun articles of aluminum and aluminum alloys does not essentially differ from that used for copper and brass, except that higher speeds are employed. The peripheral speed employed in spinning aluminum depends not only upon the blank diameter and thickness, but also upon the contour of the shell to be formed. It is usual practice to increase the speed of rotation as the diameter and thickness decrease, thus maintaining approximately the same peripheral speed.

Table 13 gives the speeds for spinning blanks of various sizes. The speeds for spinning drawn shells, given in Table 14, have proved satisfactory, although each operator will have his preference as to proper speeds.

TABLE 13

SPEEDS FOR SPINNING ALUMINUM ALLOY BLANKS

Blank Diameter, Inches	Thickness of Metal, Inch	Temperature of Metal, deg. F.	Lathe Speed, rpm
36 to 72	0.188 to 0.375	400 max.	50 to 250
24 to 36	0.081 to 0.188	Room	250 to 550
12 to 24	0.032 to 0.081	Room	400 to 700
Up to 12	0.032 to 0.051	Room	600 to 1,100

TABLE 14

SPEEDS FOR SPINNING ALUMINUM ALLOY DRAWN SHELLS

Mean Diameter of Shell in Inches	Revolutions per Minute
10–14	1,200–1,000
14–20	800– 650
20–30	550– 475
30–40	375– 325
40–50	300– 250
50–70	210– 200
70–90	175– 150

CHUCKS

If the shell is of a design which permits direct withdrawal from the chuck, a one-piece chuck is employed; but if the shell partially encloses the chuck during spinning, sectional or off-center chucks are used.

Sectional chucks are constructed so that by taking a key section out of the chuck the other pieces can be removed one at a time. The sections must fit perfectly at the joints because the slightest irregularity will be offset in the spinning and will show up as a ridge on the surface.

The off-center chuck permits spinning over a solid form which comes in contact with the work only at the point of spinning and is small enough to pass through the neck of the spun shell. It saves time where it can be used, but does not allow spinning to occur near the bottom of the shell. If an off-center chuck is used, the bottom of the drawn shells must first be formed by means of a bulging operation.

Spinning chucks are made from steel, cast iron, aluminum or hardwood, depending on the number of pieces to be spun, their size and shape, and the desired finish. For quantity and quality production the metal chuck is preferable, especially where sharp re-entrant angles are present. Hardened high polished steel chucks produce smooth surfaces and are most economical for products that are buffed or given a similar finish. Wood chucks are commonly used for spinning extremely large pieces. Such chucks can be cheaply built with laminated construction so that the contour can be readily changed. All types of chucks should be wear resistant and kept highly polished and smooth since the slightest imperfection in the surface will be transferred to the spun shape.

TOOLS

The number of tools used for spinning depends entirely on the operator and cannot be standardized. Each craftsman is apt to develop a set of tools that he prefers. Tools can be divided into three main classifications:

(1) Tools for laying the metal down against the chuck.
(2) Tools for beading.
(3) Tools for cutting or trimming.

A plain, flat, rounded end, smoothly polished hickory stick is generally used by hand-spinners for breaking down the circular blanks. The half-round all-purpose steel tools may also be used to lay the metal down against the chuck. The upper part of such tool is round and the bottom is slightly crowned rather than flat. The upper part of this tool is used to lay down the metal while the under side of the tool is used for planishing.

Beading tools are usually of the wheel type or they may be a sharp-nosed tool, and they are used to roll over or finish the edge of the shell. A plain diamond-shaped tool is used for cutting or trimming any excess metal. The tools are generally made of high-carbon steel. They are forged into shape, hardened, polished, and fastened to hardwood handles. When the shell is unusually large or the thickness of the metal is greater than approximately 0.081 inch, the spinning tools are mechanically arranged and mechanically applied against the work. Spinners' tools should be kept smooth and bright at all times if they are to give satisfactory

performance. They should be buffed lightly when they start to drag on the work and lubricated with light machine oil.

LUBRICANTS

Lubrication of the blank during spinning is necessary to prevent the surface of the aluminum alloy from becoming marred. Beeswax, tallow and petroleum jelly are suitable for small spun shapes. Large diameter blanks requiring heavy tool pressure to spin, require lubricants other than these in order to prevent the forming tool from scoring the metal surface. In such cases, ordinary laundry soap will prove satisfactory.

PROCEDURES FOR HAND SPINNING

The blank is first centered in the lathe. Centering on the chuck may be accomplished by drilling a hole in the center of the blank or by forming a dimple at the center and using this dimple to determine the position of the blank.

The lubricant is now applied to the blank. With the hickory stick the blank is laid back against the chuck an inch or so in order to "set" it. This gives an extra grip to hold the piece in place and then in progressive steps the metal is worked down on the chuck to form its contour. It is generally best to start spinning with a slow speed. If the speed is too great the blank will stand out from the chuck, and so much tool pressure will be required that excessive thinning or possibly fracture will result.

The point of the tool should touch the work off-center as the metal rotates away from the tool. It is best to work the tool back and forth in a very short radius with the movement being no more than an inch or so on either side of the fulcrum pin on the tool support. The pin should be moved frequently and kept at right angles to the point of contact. A narrow flange is left on the outside of the shell at all times, even to the final trimming operation.

In trimming, the edge is turned back slightly and the trimming tool is held lightly but firmly against it. If beading is desired, the flat tool is placed on the right side of the rim and the curl to make the bead is started with the hickory stick. The edge may now be rolled entirely over, using the beading tool to finish the job.

Intermediate chucks may be used to break down a blank if the shape is too severe to form in one spinning operation. The number of spinning chucks (or the number of breakdowns) depends on the shape of the finished product as well as its diameter with relation to the diameter of the starting blank. In general, shells with perpendicular sides require more chucks than those with sloping sides.

A form of spinning requiring high skill is called "spinning on air." A straight-sided shell, either spun in the usual manner or drawn, is inserted in a hollow chuck and held in place by a tailstock. The operator does not lay the metal against a solid chuck, but merely uses the spinning tools to form the desired shape. The work must be frequently checked against a template and corrections made in the spinning operation.

The semimechanical method of spinning differs principally in the application of the tool to the work. Two hand-operated feed screws are used to control the motion of the tool against the work. This method takes less strength than hand spinning, but requires considerable skill.

MECHANICAL SPINNING

In the mechanical spinning method the tool is rigged up to travel automatically back and forth the length of the shell. Compressed air advances the tool step by step as it presses the work tightly against the chuck. In lathes of this type, highly polished steel shoes or forms serve as the tool and are applied to the work by hydraulic pressure. Some mechanical machines have idler rolls which operate against the metal in opposite directions. These rolls substitute for the usual type of forming tool.

TUBE AND SHAPE BENDING

ALUMINUM tubing can be formed by following the same general principles and practices as used on ferrous and other nonferrous metals. The most important factors in bending of aluminum alloy tubing are the mechanical properties of the tubing itself. When a tube is bent, the material on the outside of the bend is stretched and that on the inside is compressed. Ductility is therefore an important property of the metal since it must be ductile enough to permit both stretching and compression to take place.

In addition to the ductility of the material, the size and shape of the tubing are factors that govern the bending. The sharpness of a bend depends not only upon the diameter of the tubing but also upon the ratio of wall thickness to diameter. The thinner the tubing wall the more tendency there is for rupture on the outside of the bend. Extremely thin-walled tubing has a tendency to fail by buckling on the inside of the bend. Besides fracturing and buckling, another difficulty that must be overcome in tube bending is the tendency of the tube to flatten or distort at the point of the bend. The curves in Figure 13, page 64, give bend radii which can be used as a guide for forming aluminum tubing.

Most aluminum tubing is bent cold, although in some cases hot bending may be employed to advantage since aluminum alloys become more ductile with increase in temperature. The sharpness of the bend to be made and the alloy used will determine the most satisfactory bending temperature to employ.

The general principles for bending round tubing are applicable for bending square or rectangular tubes and structural shapes. These shapes are more difficult to bend than round tubing since they have a greater tendency to collapse. Because of this, good tools of exact design and fit are of utmost importance to provide maximum support at the point of bend.

In general, when forming round, square, or hexagonal wire, acceptable bends of 180° or more may be made in these products around radii smaller than would be used in forming corresponding thicknesses of sheet in any given alloy and temper.

HAND BENDING

The sharpness of the bend and the degree to which the tube can be bent are greatly influenced by the method which is used for bending. Small diameter tubing can sometimes be bent satisfactorily by hand without internal or external support. Sharp bends can be made, providing a certain amount of flattening of the tube is acceptable. This flattening, which occurs in the convex half of the bend, relieves some of the stress during bending and thereby forestalls fracture on critical bends. The extent of flattening is dependent upon the ductility of the alloy and radius of bend. Where external support is required, a helical steel spring slipped over the tube will help keep it round at the bend.

Figure 14 shows a simple device for hand forming pipe and conduit, or other thick-walled tubing. It consists merely of a piece of pipe about three feet long with a special tee at one end. The tee is slipped over the tube at the point of the bend and a lever force applied. This type of bender and similar commercial equipment of a portable nature are widely used for installation work.

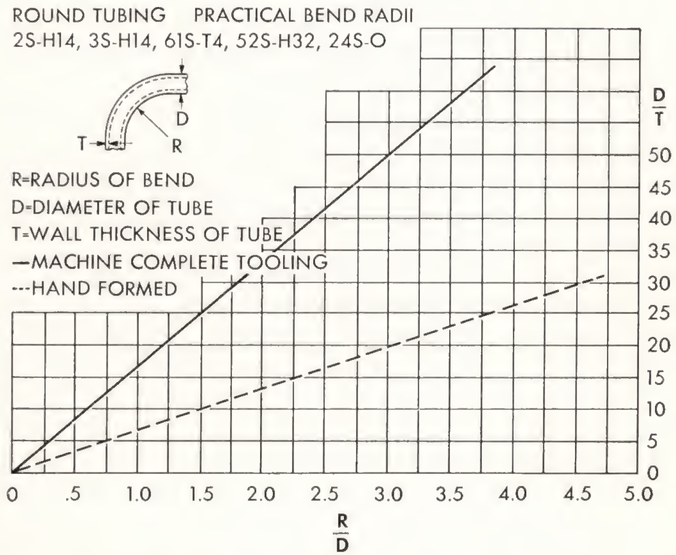


Figure 13—Bend radii for forming aluminum tubing.

Figure 14—An Allen Bender, or "hickey," is often used to bend aluminum pipe or conduit.

Hand-operated bench machines or tools, however, will produce better bends and may be necessary for difficult forming or for large production. In such equipment, the tube is usually held in a fixed position and wrapped around a form by means of a follower roll or bar. Grooving of the form and follower to closely fit the outside contour of the tube will reduce distortion.

A simple method for bending larger tubes, if the bend is not severe, is to place the tubing between two smooth pegs which are properly spaced on a ship's table or bench. (See Figure 15, page 66.) The operator pulls steadily on the free end of the tube to make the bend. It is necessary to make the bend a little at a time, moving the tube as the bend progresses, and never applying stress to the part already bent, for it may buckle. The accuracy and uniformity of the shape of the bend made by this method will depend largely upon the skill of the operator.

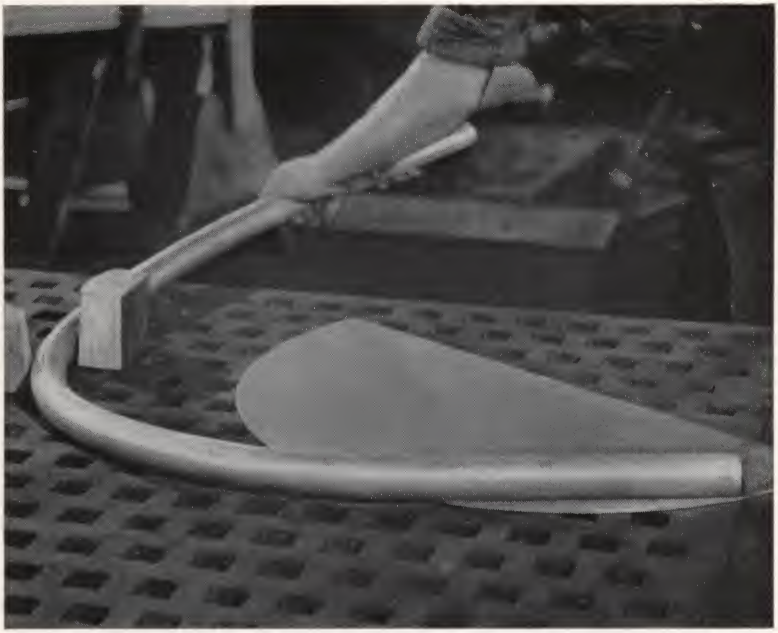


Figure 15—Bending aluminum tubing by hand between smooth pegs.

A modification of the bending method just described is the replacement of one of the pegs by a bending form around which the tubing is wrapped. A shoe or bearing block is provided for the other peg to distribute the load. This method is better than the two-peg method since it provides a bending form to which the tubing can be bent accurately and there is less likelihood that the tube will collapse on the inside of the bend, especially if the form is grooved to fit the tube. It is also an improvement over the two-peg method in that it reduces the tendency to rupture. See Figure 16.

The use of a cylinder of the desired diameter and length for the bending form on a ship's table provides a satisfactory method for making helical coils.

Power-driven rolls are also used for producing helical coils. The rolls are grooved to fit the size of tube being formed. Such a

machine has definite advantages in that coils of various diameters can be formed by merely adjusting the rolls.

FILLERS

For limited production of more difficult bends, such as small bend radii in thin-walled tubing, provision must be made to prevent distortion of the tube, and this is generally accomplished by the use of a filler in the tube. Sand is sometimes employed and then shaken out when the bend is completed.

Low melting point metal fillers may also be used for bending thin-walled tubing. These alloys usually contain bismuth, lead, tin, and sometimes cadmium. They melt at about 160°F and are easily removed by melting in boiling water or with steam.

Figure 16—Aluminum tubing can be bent satisfactorily around a bending form or hub of the desired radius.

MACHINE BENDING

Hydraulically or mechanically operated machines are used in mass production. Greater uniformity of products, closer tolerances, and smaller bend radii can be accomplished by using the proper tools and a good machine. The essential tools used on a machine are the hub, pressure block, clamping block, and mandrel generally arranged as shown in Figure 17.

The tube is slipped over the mandrel which is mounted on a rod long enough to accommodate various lengths of tubing and is placed between the pressure block and the hub, both grooved to fit the tube. The stationary pressure block must be built to withstand the wear caused by the material sliding over it. Frequently, this block is made to ride on a track and thereby move forward with the tube as it is being formed. In another common design, the pressure block is a roller which may be grooved to fit the material. Or again, the pressure block may be just a plain backup bar, so long as it fulfills the function of restraining the free end of

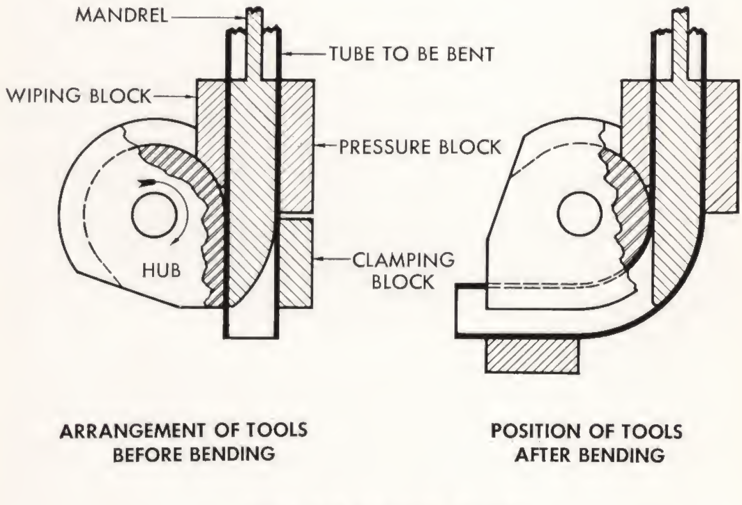


Figure 17—Tools for machine bending.

the bent material. The clamping block then holds the tube against the hub in order to make the bend when the hub is rotated. The mandrel supports the inside of the tube during bending and must be located so that its point of curvature is exactly even with the centerline of the hub (see Figure 17). If the mandrel is ahead of this point, the tubing may break; if it is too far back, the tube will flatten. When the tube slides over it, that portion subjected to bending is always at the nose of the mandrel. Maximum support is obtained with a swivelball-type mandrel. This may consist of a single or several hinged bulbs attached to the end of the mandrel. The solid, sheepnose mandrel offers support during bending intermediate between the swivelball-type mandrel and the plug-type mandrel with a blunt or rounded nose. Since the tube must slide against the blocks and over the mandrel as it is being bent, lubrication must be provided.

In addition, a wiping block is sometimes needed for bending thin-walled tubing, or for making difficult bends where greater support is needed. The block supports the tube more completely as it approaches the bend point and thus prevents buckles from forming at the inside of the bend.

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INDEX

FOR the convenience of the reader both an Index covering tables and a general Topical Index are given.

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TOPICAL INDEX

ALCOA SALES OFFICES

AKRON 8, OHIO	506 Akron Savings & Loan Building
ALBANY 7, N. Y.	90 State Street
ALLENTOWN, PA.	913 Hamilton Street
ATLANTA 3, GA.	1800 Rhodes-Haverty Building
BALTIMORE 1, MD.	400 Baltimore Life Building
BIRMINGHAM 3, ALA.	505 First National Building
BOSTON 16, MASS.	20 Providence Street, Park Square
BUFFALO 7, N. Y.	1880 Elmwood Avenue
CHARLOTTE 2, N. C.	616 Johnston Building
CHICAGO 11, ILL.	520 North Michigan Avenue
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SPRINGFIELD 3, MASS.	507 Tarbell-Watters Building
SYRACUSE 2, N. Y.	408 State Tower Building
TAMPA 2, FLA.	1004 Tampa Theater Building
TOLEDO 4, OHIO	1801 Ohio Building
VANCOUVER, WASH.	P. O. Box 120
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General Offices—Gulf Building, Pittsburgh 19, Pa.

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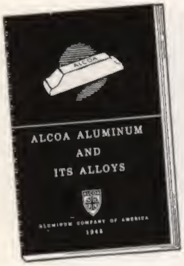

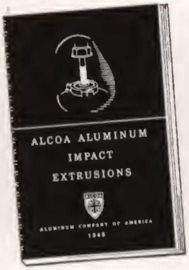

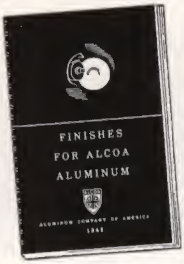

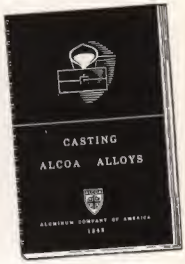

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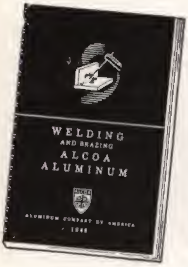

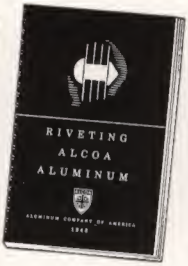

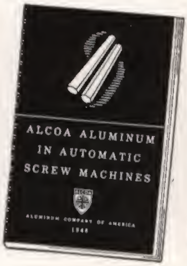

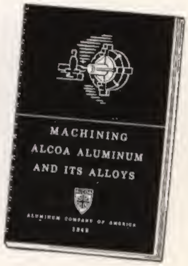

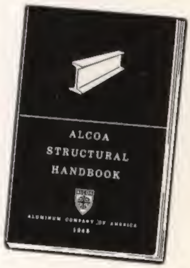

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